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Spatiotemporal Variations of Land Surface Temperature and Vegetation Dynamics Impacts on Landslide Intensity in Chattogram Hill Tracts Region of Bangladesh

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Abstract

This study was aimed at assessing the spatiotemporal variation and trends of LSTs and vegetation dynamics impacts on landslide vulnerability within CHTs region. The variation trends of land surface temperatures (LSTs) and normalized difference vegetation index (NDVI) between 2001 and 2022 were assessed using time series datasets from the moderate resolution imaging spectroradiometer (MODIS). Relevant data on the multi-variant landslides, causalities and associated datasets were collected from different archival sources and random field investigations were performed for cross verification purpose. Results showed that the variation trends of LSTs between 2001 and 2022 were mostly in an increasing mode (94% grid cells) with a yearly average LST increase of 0.34°C. Contrarily, during the same period, the variation trends of vegetation index were in a decreasing mode, while total NDVI value on average slightly increased by 0.2. Thereafter, the variation trends of LST and NDVI were significantly correlated and most of the grid cells have shown converse correlation. The landslide prone areas are mostly in the above correlation locations. The study further revealed that a total of 469 severe landslide occurrences were recorded in CHT region with Rangamati district being the most affected area with 48.6% severe landslides occurrences. Therefore, this study establishes a strong influence of climate change effects on landslide vulnerability in the CHT region. The study suggests that proper planning, policy recommendations and management of ecosystems will help reduce landslides and mountain disaster occurrences.

Keywords

Variation trends; Vegetation dynamics; Landslides; Climate change; Bangladesh

Introduction

Landslides are one of the most significant natural devastating events in mountainous areas. There are complex types of natural disaster either caused by geophysical or hydrological processes (Ahmed *et al.*, 2014). Landslides are mostly sporadic, localized and dispersed in nature that hit instantaneously and cause widespread human sufferings, including loss of lives, livelihood and ecosystem damage (Formetta *et al.*, 2014; Islam *et al.*, 2021; Jeong *et al.*, 2017; Lee *et al.*, 2017). Therefore, the occurrence of landslide is considered as one of the most catastrophic geological hazards causing extensive economic losses, physical damages and fatalities.

However, landslide or slope failure may be initiated by natural processes or by human intervention. The natural processes involve the slope, topography, relief, geological condition, materials, geospatial location, weather conditions, land use and land cover settings as well. Prior to the post-industrial revolution, developed and developing nations in a race to attain a peak in their industrialization, economic growth and wealth development are producing excessive amount of greenhouse gases, especially carbon dioxide (CO_2) (CPD, 2019; Ganguli, Islam and Garai, 2018; Islam *et al.*, 2021; Mohiuddin *et al.*, 2021). In order to accelerate economic development, most countries are fully concentrated on infrastructural development and pay little or no attention on its impact on the natural environment, ecology and ecosystem. The ultimate changes, therefore, greatly influenced the global climate change. Therefore, the consequence of climate change and associated phenomena have great impacts over regional weather conditions, especially, on land surface temperature and rainfall, plant growth, photosynthesis, etc. (Alauddin *et al.*, 2020; Ghosh *et al.*, 2020; Islam and Ma, 2018; Islam *et al.*, 2019; Zhu *et al.*, 2020). The appropriate level of vulnerability can be estimated if the climatic variables and their effects on surface temperature, rainfall, and vegetation dynamics could be simulated by numerical models (Ciccarelli *et al.*, 2008; Diffenbaugh *et al.*, 2013; Giorgiand Lionello, 2008; Islam and Ma, 2018; IPCC, 2014; Lo Presti *et al.*, 2015; Turco *et al.*, 2015). Hence, evaluated climate change level would estimate the single slope or entire catchments, landslide frequencies, extent, and variations remain to be understood (Ciervo *et al.*, 2017; Coe, 2016; Coe *et al.*, 2012; Corominas, 2000; Gariano *et al.*, 2016; Gariano *et al.*, 2017b; Hanson *et al.*, 2012; Rianna *et al.*, 2017; Simonovic *et al.*, 2016).

The mountain slope and landslide frequencies influenced by climate change are undisputable. But, the quantitative estimation of the effects of climate change, regional environmental sustainability, and landslide vulnerabilities is a quite complex phenomenon. The evaluation is made more difficult by the spatial and temporal scales, which are acting in partial overlap with climate and landslides. As a result, additional research and knowledge in hydrology, climatology, geology, hydrogeology, physics, environmental science, soil science, geotechnical science, and social science are necessary. The climatic, environmental, demographic, and economic changes are highly correlated and always produced complex feedbacks in the occurrence and variation of landslides. As a result, a multidisciplinary and holistic approach is required. The evaluation and subsequent mapping of landslide vulnerability is a well-known practice that offers the opportunity for a dynamic, integrated, and ongoing management of the territory and its sudden modifications (Devkota *et al.*, 2013; Kavzoglu *et al.*, 2014; Pellicani *et al.*, 2014; Pham *et al.*, 2016).

The Global Climate Risk Index 2021 rating countries suffering from extreme weather events and weather related losses between 2000 to 2019 ranked Bangladesh as the 7th most vulnerable country under climate change effects although being one of the zero-liable greenhouse gas (especially CO_2) emitting country (Eckstein *et al.*, 2021). Moreover, research findings during the last couple of decades show that Chattogram hill tracts (CHT) region has increased land surface temperature, with a conversely correlated normalized difference vegetation index (NDVI) that is decreasing, thereby, threatening ecosystem sustainability (Islam *et al.*, 2018; Islam *et al.*, 2019; Islam *et al.*, 2021). As a result, the combined effects of climate change in the CHT region have been shown to increase the risk of landslides and influence the amount, variation, and duration of monsoon rainfall (Hossain and Mohiuddin, 2020). In the meantime, rising soil temperatures are altering crop diversity, decreasing fertility, and crop production. The CHT region experiences deforestation and land degradation resulting from environmentally unsustainable activities like shifting cultivation, logging, and cultivation on steep slopes.

Although, it is difficult to pinpoint the specific causes responsible for global environmental change in the area, one of the most important factors is temperature variations and global warming. Therefore, this study is aimed at assessing the spatiotemporal variations of land surface temperature (LST) and vegetation dynamics impacts on the intensity of landslide vulnerability at the Chattogram hill tracts (CHT) region of Bangladesh between 2001 and 2022. It sets out to answer the following questions: what is the spatial and temporal variations and trends of land surface temperature? What is the vegetation dynamics observed as well as the intensity of landslide vulnerability in the area? What is the correlation-coefficient between the variation trend of LST (evidence of climate change) and NDVI (vegetation dynamics) and their combined effects on the intensity of landslide vulnerability?

Materials and Methods

Study Area

This study was carried out within the territory of Chattogram Hill Tracts (CHT), the only extensive hilly area in Bangladesh located between latitude 21^0 25' N to 23^0 45'N l and longitude 91^0 54'E to 92^0 50'E in the southeastern part of the country (Figure 1) (MoCHT, 2023) with a total surface area of 13,184 sq. km. The CHT region combined with the three mountainous districts of Rangamati, Khagrachhari and Bandarban is bordered by Myanmar on the southeast, the Indian state of Tripura on the north, Mizoram on the east and Chattogram district on the west (Adnan and Dastidar, 2011; Ghanea, 2005). The mountainous rugged terrain with thick forests, lakes and water falls gives the area a unique landscape from the rest of Bangladesh. Like other mountainous areas in South and Southeast Asia, the CHTs are undergoing deforestation and land degradation arising from environmentally unsustainable activities such as tobacco cultivation on steep slopes, shifting cultivation and logging.

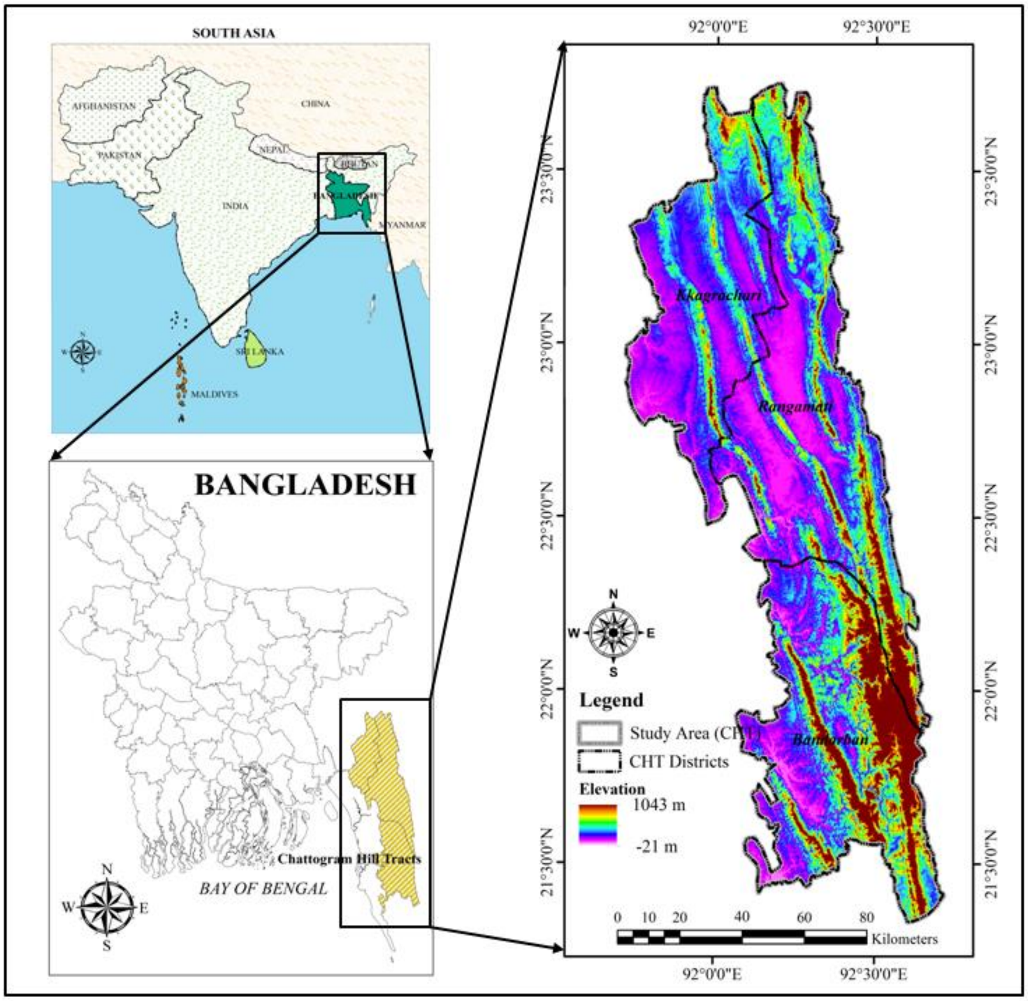

Figure 1: Geographical location of the study area in Bangladesh with elevation DEM

Data Collection

Datasets for Variation Trends of LST and NDVI

To evaluate and assess the spatiotemporal variation trends of land surface temperature (LST) and vegetation dynamism (NDVI) of CHT region, comparatively high consistent and multi-resolution synthetic time-series of the MODIS LST 16-days and MODIS NDVI 32-days datasets from 1 January 2001 to 31 December 2022 time period were generated. Moreover, the datasets were evaluated according to the CHT region of Bangladesh to ensure that its accuracy can meet the needs of an analysis of spatiotemporal climate change. The Land Processes Distributed Active Archive Center (LP DAAC) version v006 managed by the National Aeronautics and Space Administration (NASA) Earth Science Data and Information System Project provided the time series MODIS data products for the LST and NDVI with a 1 kilometer spatial resolution for clear sky days and nights.

Two of the MODIS Terra 8-day LST composition products (MOD11A2, C6) were chosen because they correspond precisely to the terra platform's ground track repeat period (Wan, 2014). For the purpose of evaluating the dynamics of vegetation, the MODIS Terra monthly NDVI products (MOD13C2, C6) utilized 16-day cloud-free spatial composites with a 1 kilometer spatial resolution between January 1, 2001, and December 31, 2022. In order to eliminate the influence of bare and sparsely vegetated regions, only grid cells with a value greater than 0.1 were used for the study (Piao *et al.*, 2006; Zhou *et al.*, 2001) as well as to decide the developing season (Tan *et al.*, 2018).

Landslides Data

This study obtained records of landslide occurrences from the Disaster Management Bureau (DMB) and District Offices of the People's Republic of Bangladesh for the combined three districts of Khagrachari, Rangamati and Bandarban. Despite the fact that the CHT region experiences a significant number of landslides annually, this study only considers those that have impacted human lives, existence, and livelihoods. In addition, this study was constrained by the fact that the majority of the CHT region's sensitive and wild areas are well-known.

Statistical Analysis

Time Series Analysis of LST and NDVI

The annual values of surface temperatures and vegetation were calculated by averaging the inter-annual datasets from MODIS LST and NDVI. However, the annual change tendencies were quantified in order to evaluate the variation trends of the MODIS LST and NDVI spatial patterns. Annual time series were produced by processing monthly time series. The time series has a length of n = 22, spanning from 2001 to 2022, for each pixel. Based on linear regression, change rate and change range were used to estimate regional tendency and appeared unaffected by potential constant biases in the data (Li *et al.*, 2018; Stow *et al.*, 2001; Stow *et al.*, 2003; Tan *et al.*, 2017; Tan *et al.*, 2018). Therefore, the slope and range were utilized to evaluate the LST and SINDVI inter-annual variations (Li *et al.*, 2018; Stow *et al.*, 2003; Tan *et al.*, 2018). From 2001 to 2022, the slope shows the change rate for each pixel, which was calculated using linear regression and ordinary least-squares estimation. In estimating linear regression, the following ordinary least squares (OLS) method was used:

$$Slope = \frac{n \times \sum_{i=1}^{n}(i \times Ai) - \sum_{i=1}^{n} i \times \sum_{i=1}^{n} Ai}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \tag{1}$$

where n is the length of the time series that was studied. In this paper, n is equal to 22 and i is the number of years; and A_i refers to the *NDVI* or *LST* for the *i*th year. When the slope values are close to *0*, the trend has not changed significantly. Slope greater than *0* indicates an expanding trend, while slope less than *0* indicates a decreasing trend (Chen *et al.*, 2010).

The ranges of variations in the LST and NDVI cover, or the total change between 2001 and 2022, were then calculated as follows:

$$Range = Slope \times (n-1) \quad (2)$$

where *n* is the length of the time series and is expressed as *n = 1,2,...,22*.

Accuracy Assessment

The thematic datasets of MODIS LST and MODIS NDVI products accuracy were assessed randomly in order to evaluate the quality of research results and ensure that geographic data are used appropriately. Thematic accuracy refers to a comparison between attributes or labels of mapping elements which are regarded as true and the reference that is expected to be true. However, the fundamental practice recommends that thematic accuracy assessments be as follows: each class category points out for accurate assessment and a statistical error matrix (Congalton and Green, 2009). Google Earth’s high-resolution imagery was used for collecting ground truth samples. Then, ground points were selected manually, which were cross validated using the formula:

$$Overall\ Accuracy = \frac{TCS}{TS} \times 100$$

The image classification accuracy was assessed by calculating the Kappa coefficient as follows:

$$Kappa\ Coefficient = \frac{(TS \times TCS) - \sum(Total\ Pixel\ Coloum \times Total\ Pixel\ Row)}{TS^2 - \sum(Total\ Pixel\ Coloum \times Total\ Pixel\ Row)} \times 100$$

where, *TS* = Total sample pixel; *TCS* = Total correct sample pixel.

The Kappa statistics is an estimate of the measure of overall agreement between image data and the reference (ground truth) data. Its coefficient falls typically on a scale between 0 and 1. It is often multiplied by 100 to give a percentage measure of classification accuracy. Therefore, the accumulated remote sensing thematic datasets of MODIS LST and MODIS NDVI accuracy was assessed from 100 randomly selected pixels from both MODIS LST products and MODIS NDVI products, respectively, for verification. Thereafter, all the selected 200 pixels were verified with a spatial thematic map of Landsat. The calculated error matrix with an overall accuracy of between 85-96% and a Kappa coefficient between 0.84 and 0.92 was deemed highly acceptable for further assessment and analysis as well.

To evaluate the significance of monotonic trends in the LST and NDVI time series, the conventional non-parametric Mann–Kendall test (M–K test) was extensively used (Gedefaw *et al.*, 2018; Khambhammettu, 2005; Vousoughi *et al.*, 2013).

Correlation Analysis

The evaluated variation trends of LST and NDVI were subjected to correlation analysis to determine the relationship between the coefficients (Stow *et al.*, 2010). The correlation was calculated using the annual average values of each pixel's annual composite values of LST (greater than 1.96 K) and NDVI (greater than 0.1) across the entire 22-year time series as follows:

$$r_{XY} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \tag{3}$$

where r is the correlation coefficient between X and Y. The values of the first year are X_i and Y_i, and the annual average values of the time series are X and Y. In this paper, n is 22 and i = 1, 2,...22.

Result and Discussion

Spatiotemporal Occurrence of Landslides in CHT Region during 2001-2022

Topographically, Chattogram hill tracts (CHT) is the only extensive hilly area with a mountainous rugged terrain covered with thick forests, lakes and falls that gives it a unique nature. Due to excessive amount of rainfall during the monsoon season (June–September), CHT region frequently faces severe landslide hazards. However, three distinct groups of communities known as urbanized hill (Bengali), tribal, and stateless Rohingya refugees have been living in the CHT region for a long time (Ahmed, 2001). The physical, social, economic, environmental, institutional, and cultural aspects of these communities contribute to their vulnerability to landslides.

Results revealed that of the 469 landslide events were assessed in the CHT region between 2001 and 2022 (Figure 2), 48.6% (228) of the landslides occurred within the Rangamati districts affecting the district town and its surroundings. Bandarban, the largest district not only in the CHT region but also the largest in Bangladesh, was second in terms of the landslide severity with a 29.4% (138) occurrence, while the Khagrachari district was the least affected with an occurrence rate of 22% (103).

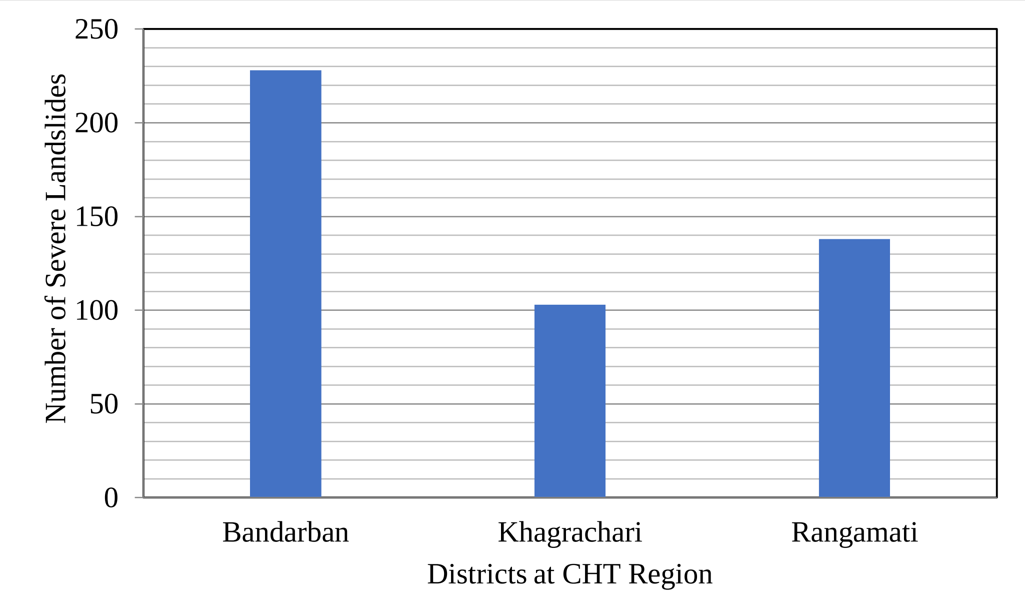

Figure 2: Number of occurrences of severe landslides in CHT region between 2001 and 2022

In addition, the geospatial locations of landslide hazards within the region's three districts were evaluated and the results are presented in figure 3. Results revealed that landslide occurrences are unevenly distributed despite the fact that they occur frequently and increase with each monsoon in a specific region with visible physical and natural disturbances. In the CHT region, where 95% of landslides occurrences were recorded, 31 severe zones of landslide hazards were identified. Therefore, Rangamati, Khagrachari, and Bandarban districts have 13, 11, and 7 zones in the zonal distribution, respectively.

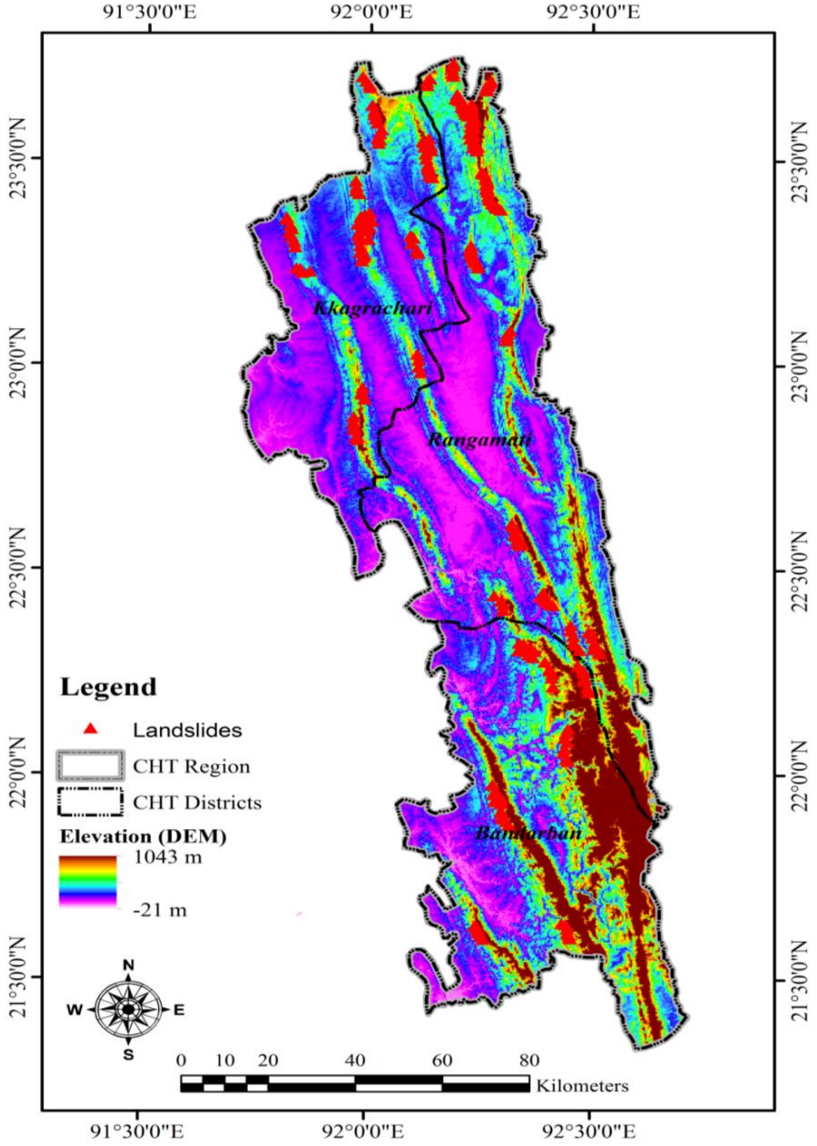

Figure 3: Geospatial distribution of landslides occurrences in CHT from 2001 to 2022

Variation/Trends of Land Surface Temperature within the CHT Region of Bangladesh

Remotely sensed land surface temperature (LST) is currently regarded as a more reliable and well-known climate change indicator. Results showed that the frequency and intensity of severe rainfall events, a primary cause of shallow, swift-moving landslides that result to a large number of fatalities, are on the increase as a result of global warming (Figure 4). However, it is normal to anticipate an increase in the number of people at risk from landslides.

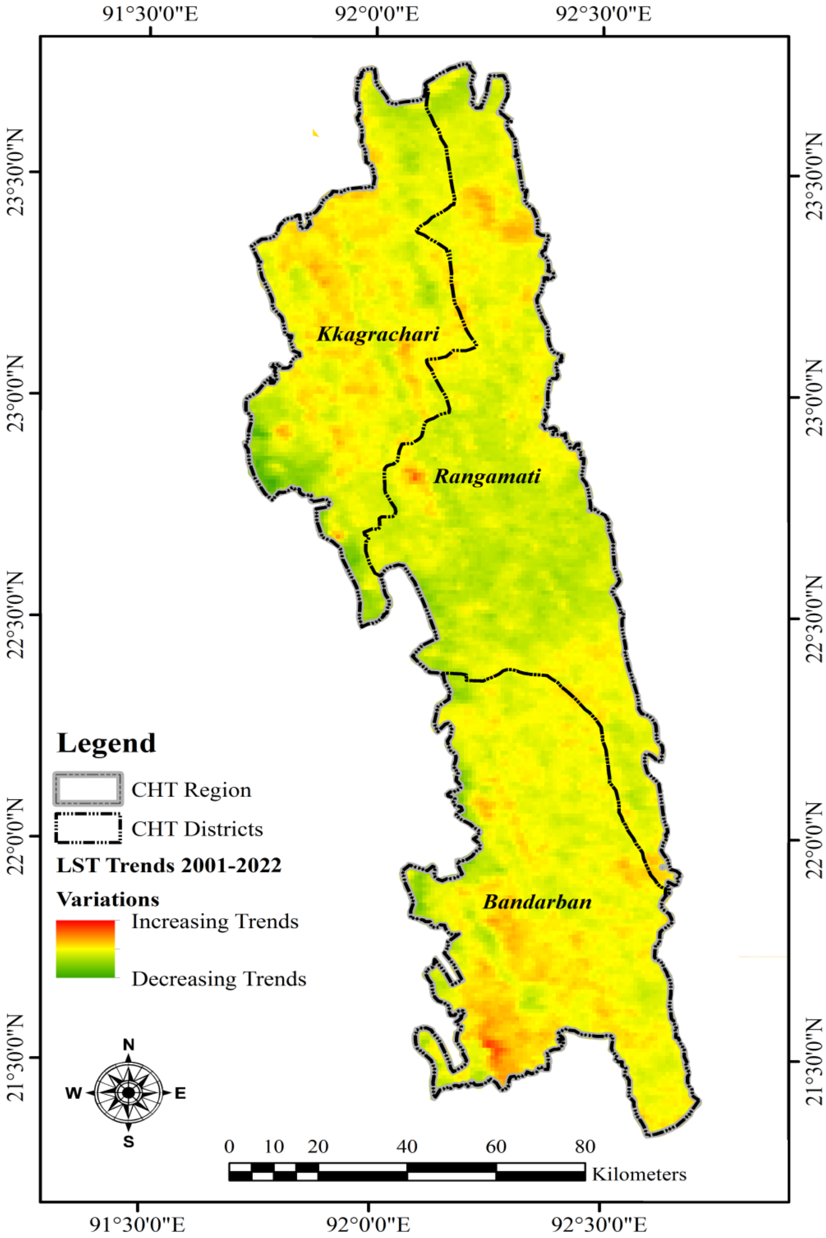

Figure 4: Variation trends of LST in the CHT region between 2001 and 2022

Therefore, using MODIS time-series LST products of days and night time, this study evaluated the variation trends of LST between 2001 and 2022. The variation trend results showed that about 83% grid cells showed an increasing trend that clearly indicate an increasing land surface temperature all over the region. However, an average increase of 0.34^{0}C in surface temperature was recorded within the 22 years period. Geospatial LST increasing rate was, therefore, highest in Khagrachari district compared to others.

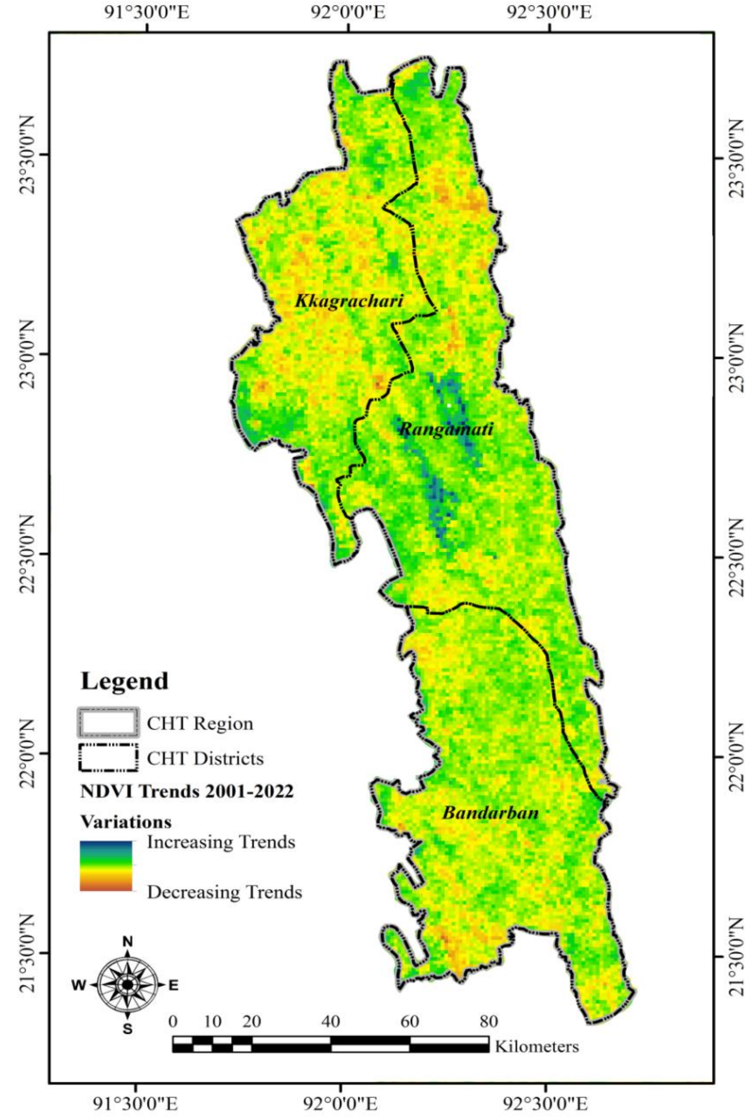

Figure 5: Variation trends of NDVI in the CHTs region between 2001 and 2022

Variation/ Trends of Vegetation Dynamics

Traditionally, the CHT region of Bangladesh is covered by the evergreen forest, which forms a part of the globally recognized Indo-Burma mixed vegetation. Some researchers have identified that the vegetation index is decreasing especially in the high hills region due to increased agricultural practices, and in the low hills region due to urbanization resulting from conversion of vegetation to urban built up areas (Ahmed, 2017). Results from MODIS time series NDVI datasets analysis of 2001 to 2022 showed that 53% of the grid cells have negative variation trends, which prove vegetation coverage is decreasing (Figure 5). However, on an average in the last 22 years, a very little increase in the index by 0.2 was noticed while surrounding areas of the Southeastern region recorded an overall increase of 4.0 NDVI index during 2001-

2016 (Islam *et al*., 2018). Geospatially distributed variation trends of NDVI showed that Khagrachari and Rangamati districts are highly vulnerable compared to other regions.

Spatiotemporal Correlations of LST, NDVI and Landslides Intensities

Results of the Pearson correlation coefficient showing the variations/trends of LST and NDVI showed that most of the grid cells recorded a moderately significant relationship or strongly negative relationship between the variables observed for LST and NDVI. Moreover, partial correlation of landslide prone areas with the identified coefficient locations revealed a highly negative correlation (Figure 6). Some locations, however, were having more intensity of landslides occurrences. Therefore, the study observed that though increased land surface temperature in the Chattogram Hill Tracts (CHT) influence vegetation growth. A decrease in NDVI was observed due to anthropogenic activities in the area. The increased LSTs and decreased NDVI together influence landslide vulnerabilities.

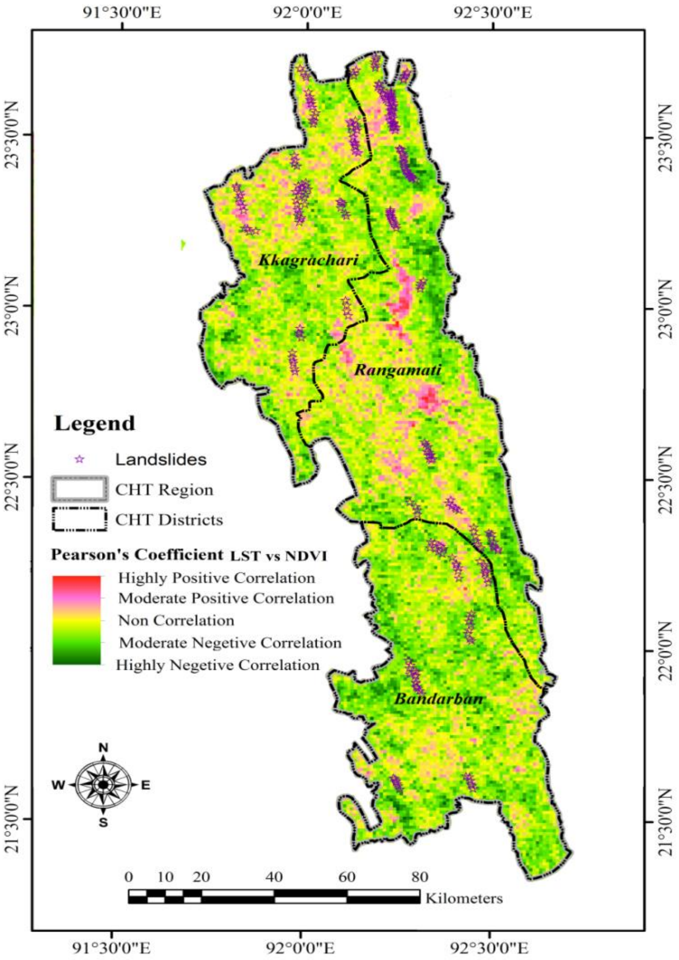

Figure 6: Geospatial correlation coefficients and partial correlations of variation /trends of LST, NDVI and landslide occurrences

The disaster scenario of landslides is global in its origins, which means that the solutions need to be adapted from different directions. In the past years, landslides have caused many casualties and caused serious damage to essential infrastructure, ecosystems, livelihoods and local economies in Chattogram hill tracts (CHT) of Bangladesh (Rabby and Li, 2019). In particular, the risk of landslides will be borne by those communities residing in mountainous areas such as Khagrachhari, Rangamati and Bandarban where there are frequent landslides obstructing road and river transport development in the area (Ahmed, 2021). Therefore, risk awareness through environmental education and sensitization and the development of a strict action plan are much needed to halt hill cutting and develop temporary settlements on the hills.

Conclusion and Policy Recommendations

Landslides are highly complex disasters that differ from one geographical location to another. In mountainous terrain, landslides are a natural geological phenomenon. Their mechanism and evolution are closely related to the geological conditions and environmental factors. Therefore, landslides in the CHT region are controlled not only by geological forces, lithological structure, and other crustal internal factors, but also by topography, land cover, amount and duration of precipitation, agriculture, and environmental conditions (Shan *et al.*, 2014). The global climate change, especially, land surface temperature changes and its associated effects have a great impact. Projected changes in rainfall duration and quantity can be used to determine the extent of slope failure in the CHT region. Over the past few years, rainfall patterns in Bangladesh have also been changing and short periods of heavy rains are common. They are more likely to cause landslides on unstable slopes (Sassa, 2009).Therefore, rainfall is very important in landslide vulnerability assessment as well as land use and land cover changes, hill cutting, environmental degradation, cultivation, etc. However, this study has considered them as limitations and opportunities. The LST and NDVI were seen to have an impact on landslide hazard in the study area.

The CHT region remains vulnerable to landslides and this is a major environmental challenge. Thus, there is a need to put in place urgent and robust measures targeted at reducing landslide vulnerabilities and building a resilient community by taking into consideration the factors triggering vulnerabilities in the area which has largely been ignored in the past. Urgent actions are needed to promote plans for the protection of vulnerable areas.

1. There should be a strict enforcement and implementation of environmental protection laws in the area.
2. Resettlement and relocation schemes should be implemented to reduce human casualties in the hills.
3. Proper land use planning, implementation and enforcement are very necessary to abate landslide disasters in the area. With a good land use plan, marginal areas uninhabitable for human habitation should be well marked out and construction needs to be prohibited in such areas. Building permits must be imposed and controlled to ensure that they are strictly followed.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*
Conceived and designed the research or analysis	Yes	Yes	No	No
Collected the data	Yes	Yes	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	No	No
Critical revision of the article/paper	Yes	No	Yes	Yes
Editing of the article/paper	Yes	No	Yes	Yes
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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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